Executive Summary, Research Readiness Level Assessment, and Technology Transfer

Development of High-Performance Rapid Patching Materials for Pavement Repair

Research Objectives

The goal of this study was to develop cost effective and durable high-performance rapid patching materials for full depth concrete pavement repair.

To achieve this goal, two specific objectives of this study were to:

1) Develop cost-effective patching materials that provide sufficient early strength (a minimum 3,000psi compressive strength in 4-8 hours) for proper traffic opening; and

2) Ensure long-term performance by diminishing durability issues (such as ASR) in the current PR mixes.

Research Benefits

The new repair mixture has appropriate workability and constructability for the easy placing in the field, as well as adequate early-age strength, long-term durability, and volume stability that meet NDOT specifications.

The success of the research resulted in cost savings and durable patching materials for concrete pavement repair.

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Background

Concrete pavement distresses resulting from freeze/thaw (F/T) deterioration, alkali-silica reaction (ASR), and chemical attacks may cause different forms of deterioration, including scaling, cracking, breaking, chipping, and fraying. Concrete pavements exhibiting severe distresses such as transverse cracks, shattered slabs, and corner breaks require patching are commonly observed in concrete pavement in Nebraska. Due to the opening requirement of the pavement to traffic after the placing of repair concrete, it is essential to achieve high early strength. To ensure high early strength, our current patching mix (i.e., PR in the NDOT specification 1002.02) requires a minimum cement content of 752 or 799pcy for PR1 and PR3 mixes respectively. Besides the high associated cost, the high cement content tends to result in a less stable mix with a high drying shrinkage, high autogenous shrinkage, high heat of hydration, and high cracking potential. The mixes also exclude the use of fly ash, which makes it vulnerable to various deteriorations, particularly ASR. To reduce the material cost and premature failures of pavement repair, patching materials that develops early strength and is durable is needed.

Conclusion

Concrete pavements exhibiting severe distresses which require patching are commonly observed in the concrete pavement in Nebraska. Due to the requirements of opening pavement to traffic after placing the rapid patching materials, it is essential for that concrete to achieve high early strength. To ensure this, a high cement content and chloride-based accelerators are currently used in the Nebraska Department of Transportation (NDOT) Portland cement-based rapid-patching materials. Besides its associated high cost, high cement content tends to result in a less stable mix with high shrinkage, high heat of hydration, and high cracking potential. In addition, using chloride-based accelerators has adverse effects on concrete durability. Also, the effect of the low ambient temperature has a considerable impact on the strength gain and needs to be assessed to estimate the traffic opening. Therefore, this project studied the performance of rapid patching materials for three different aspects: reducing cement content through optimizing aggregate gradation, replacing conventional calcium chloride with a non-chloride accelerator, and partial replacement of type I/II or type III cement with type IP cement. Fresh, early-age, mechanical, durability performance and constructability were evaluated on each of the developed mixture design. The performance of developed mixes at low ambient temperature (50 and 60°F) was also evaluated. Overall, it appears that, with the optimized aggregate gradation, mixes with reducing cement content by up to 100lb/yd3 together have good constructability and can meet the general requirements, which were confirmed from the evaluation of key parameters, including early-age compressive strength, modulus of rupture, bond strength, surface resistivity, drying shrinkage, and alkali-silica reaction (ASR) resistivity. The nonchloride-based accelerator showed promising behavior as an alternative accelerator. The developed mixes exhibit satisfies early-age and 28-day compressive strength, modulus of rupture, and bond strength. The free shrinkage can be reduced by up to 30% with the lower cement content. The tendency of ASR deterioration can be reduced significantly by replacing 50% Type III cement with Type IP cement. Finally, as expected, when experiencing a low ambient temperature, strength growth can be delayed and employing PR3 mixes will be a more viable option to reduce the traffic closure durations.

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NDOT Recommendations Based Off of Research Project – 2020 – RRL4

The Department will follow up during this year construction season. Additional mechanical and durability testing will be performed by Materials & Research in a construction setting vs a lab setting. To ensure the following:

- Minimum 3,000 psi compressive strength in 4-8 hours for proper traffic opening.
- Ensure long-term performance by diminishing durability issues, such as ASR.
  - *As provided by Wally Heyen, Lead TAC Member*

NDOT Recommendations Based Off of Research Project – 2025 – RRL5

The NDOT followed up with this research during the 2022 construction season on the Columbus South Highway 81. Eight total pavement repair (PR) mixes were designed and cast: four pavement repair mixes using Type I/II cement (PR1) and four pavement repair mixes using Type III cement (PR3). Each pavement repair class consisted of the standard PR mix as Control, a reduced cement content mix with optimized aggregate gradation, and two mixes with partial replacement of Type I/II or Type III with Type IP NDOT evaluated the mixes for the following:

1. A minimum 3,000 psi compressive strength in 4-8 hours for proper traffic opening.
2. Durability Testing: Freeze and Thaw and NDOT Wet and Dry.

Class of Concrete	Cement Type	Cementitious Materials (lb/cy)	Total Aggregate Min-Max	Air Content Min-Max	% Ledge Rock	W/C Max	Required Minimum Strength (psi)
PR1 (Control)	I/II	752	2500-2950	6.0-8.5	30±3	0.36	3500
PR1-2	I/II	658	2500-2950	6.0-8.5	45±3	0.36	3500
PR1-4	IP/I-II	752 (25% IP / 75% I/II)	2500-2950	6.0-8.5	30±3	0.36	3500
PR1-5	IP/I-II	752 (50% IP / 50% I/II)	2500-2950	6.0-8.5	30±3	0.36	3500
PR3 (Control)	III	799	2500-2950	6.0-8.5	30±3	0.36	3500
PR3-2	III	700	2500-2950	6.0-8.5	45±3	0.36	3500
PR3-4	IP/III	800 (50% IP / 50% III)	2500-2950	6.0-8.5	45±3	0.36	3500
PR3-5	IP/III	800 (30% IP / 70% III)	2500-2950	6.0-8.5	45±3	0.36	3500

Based on mechanical and durability testing results, PR1-4 and PR3-4 were chosen for further testing because of their strength gain and freeze-thaw cracking resistance. PR1-4 reached 3000 psi by 6 hours and PR3-4 reached 4011 psi by 4 hours. Furthermore, partial replacement of Type I/II and Type III with Type IP bolstered the mixes' freeze-thaw durability. Visual inspection of the Columbus South Highway mixes will continue out until 2027.

In June 2025, PR1-4 was used in place of PR1 for a repair project on the N-64 – L28B with great results and has been added to the pavement repair specifications. Pavement Design will continue using the mix design as needed for repairing pavements that are relatively young in service life.

- *As provided by Wally Heyen, Lead TAC Member*

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Technology Transfer

Transportation Research Board (TRB) papers

- S. Gholami, J. Hu, Y. Kim, and M. Mamirov, Performance of Portland Cement Based Rapid Patching Materials with Different Cement and Accelerators Types, and Cement Contents, Journal of Transportation Research Record, 2019, Vol. 2673 (11), pp. 172-184. https://journals.sagepub.com/doi/abs/10.1177/0361198119852330?journalCode=trra

Conference Presentations

- S. Gholami, J. Hu, and Y. Kim, "Invited Talk: Development of High-Performance Rapid Patching Materials for Pavement Repair", Nebraska Concrete Pavement Association Annual Workshop, Lincoln, NE, January 21, 2020.
- M. Mamirov, S. Gholami, J. Hu, Y. Kim, "Sustainable Pavement Concrete and Pavement Patching Materials through Aggregate Gradation Optimization and Reduced Cement Content", International Airfield and Highway Pavements Conference, Chicago, Illinois, July 21-24, 2019.
- S. Gholami, J. Hu and Y. Kim, Performance of Portland Cement Based Rapid Patching Materials with Different Cement and Accelerators Types, and Cement Contents, Transportation Research Board Meeting, Washington DC, January 13–17, 2019.

Research Readiness Level (RRL) Assessment

RRL 5

Level 5: Standard Practice

Research/Technology refined and adopted by the Department.

This brief summarizes Project SPR-P1 (18) M071
"Development of High-Performance Rapid Patching Materials for Pavement Repair"
Nebraska Department of Transportation Research Program